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TRANSIENT EXCITATION AND MECHANICAL ADMITTANCE TEST TECHNIQUES FOR PREDICTION OF PAYLOAD VIBRATION ENVIRONMENTS

Daniel D. Kana and Luis M. Vargas

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16. Abstract

Transient excitation forces were applied separately to simple beam-and-mass launch vehicle and payload models to develop complex admittance functions for the interface and other appropriate points on the structures. These measured admittances were then analytically combined by a matrix representation to obtain a description of the coupled system dynamic characteristics. Response of the payload model to excitation of the launch vehicle model was predicted and compared with results measured on the combined models. These results are also compared with results of earlier work in which a similar procedure was employed except that steady-state sinusoidal excitation techniques were included. It is found that the method employing transient tests produces results that are better overall than the steady state methods. Furthermore, the transient method requires far less time to implement, and provides far better resolution in the data. However, the data acquisition and handling problem is more complex for this method. It is concluded that the transient test and admittance matrix prediction method can be a valuable tool for development of payload vibration tests. Suggestions are given for further refinement of the method.

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by

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SUMMARY

Transient excitation forces were applied separately to simple beam-and-mass launch vehicle and payload models to develop complex admittance functions for the interface and other appropriate points on the structures. These measured admittances were then analytically combined by a matrix representation to obtain a description of the coupled system dynamic characteristics. Response of the payload model to excitation of the launch vehicle model was predicted and compared with results measured on the combined models. These results are also compared with results of earlier work in which a similar procedure was employed except that steady-state sinusoidal excitation techniques were included. It is found that the method employing transient tests produces results that are better overall than the steady state methods. Furthermore, the transient method requires far less time to implement, and provides far better resolution in the data. However, the data acquisition and handling problem is more complex for this method. It is concluded that the transient test and admittance matrix prediction method can be a valuable tool for development of payload vibration tests. Suggestions are given for further refinement of the method.

I. INTRODUCTION

With the advent of the space shuttle and its potential variety of payloads, the requirement has arisen for the development of simple, cost effective and practical procedures for vibration qualification tests of payload structures having a wide range of dynamic characteristics. The feasibility of applying admittance test techniques to the development of these procedures has been demonstrated for a simple structural model in an earlier part of the present work.[(1)*] It was recognized that characteristics of the orbiter alone will not change from flight to flight, even though those of the payload will. If appropriate admittances for the payload and orbiter are determined individually, the results can be combined analytically to predict the installed payload environment for various flight conditions. Therefore, the dynamics of the orbiter need be determined only once. Subsequently, each payload may be tested alone since the dynamic coupling between the two can be predetermined and programmed as part of the excitation forces at the interface points.

The work reported herein expands upon the earlier effort, in that the same simple payload and orbiter component models are tested for dynamic characteristics, and the same admittance matrix prediction techniques are used for predicting combined response. However, a transient excitation force is used, instead of a steady state sinusoidal force, to obtain component dynamic characteristics. Briefly, the technique consists of imparting a transient swept sinusoidal force to the structure of either the orbiter or payload model at some appropriate point, and recording response transients at the same and/or other points. The transient data were digitized, Fourier transforms were computed, and subsequently all pertinent input and transfer admittances were determined. Thereafter, use of the admittances for prediction of combined system responses followed the same procedures of the earlier work.

The impetus for use of transient rather than steady state sinusoidal test techniques arises from the significantly shorter time requirement for acquiring transient data. However, the most suitable form of transient, as well as parameters associated with data acquisition, had to be determined as part of the study, sometimes through a trial and error process. Generally, it is found that the transient test techniques can be used quite successfully in the combined system response prediction procedures. However,

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*Superscript numbers in parentheses refer to references given at the end of this report.

the results of this study emphasize that particular care must be exercised in assuring that sufficient dynamic range is maintained in the data. Recommendations are given for appropriate measures that must be taken in applying the method.

The authors wish to express their sincere appreciation to Mr. George Downey, Jr. for conducting the experiments, to Mr. Arthur F. Muller for his assistance in performing the analog to digital conversions, and to Mr. Herbert G. Pennick for his assistance in computer programming.

II. BACKGROUND

The purpose of this section is to review the results of the previous study which included steady state sinusoidal excitation, and provide a general description of transient test techniques. Detailed procedures for application of the method to the problem at hand, as well as a comparison of results from the use of both methods will be given in later sections.

A. Steady State Sinusoidal Test Admittance Techniques

The use of admittance matrix techniques(1) for the prediction of the response of a payload to an external excitation applied to the orbiter yielded favorable results when based on steady state sinusoidal admittance measurements. A brief summary of this earlier work will be given, since the same admittance matrix techniques were used in the current study.

Essentially, the experimental part of the earlier study consisted of applying a steady state sinusoidal excitation to the flexible payload model shown in Figure 1 at one of the attach or input points (points 1-4), and measuring the response or admittance of the same and/or other points. Measurements were performed at twenty frequencies chosen as a good representation of resonance, anti-resonance, and between-resonance frequencies. Similar tests were performed on the rigid body payload model shown in Figure 2. Two basically different payload models were included to allow a better determination of the validity of the method. Additional similar tests were performed on the orbiter model shown as the noncrosshatched part in Figure 3, for points 1-4 and 8. Note that for clarity, the elastic payload model has been shown installed, but crosshatched. However, it is understood that tests performed on the orbiter model alone include only the noncrosshatched part of the schematic shown in Figure 3. Position 8 on the orbiter was arbitrarily selected as the input force point for prediction of combined system responses. The individual payload and orbiter test results were then substituted into the admittance matrix equations to yield a prediction of the payload response to an external excitation applied to the orbiter.

A detailed development of the admittance matrix technique is given in Reference 1. Here, we will only summarize the final result to be used in the present study. The admittance matrix prediction equation for the acceleration response of the payload at point 5 (see Figure 1) is:

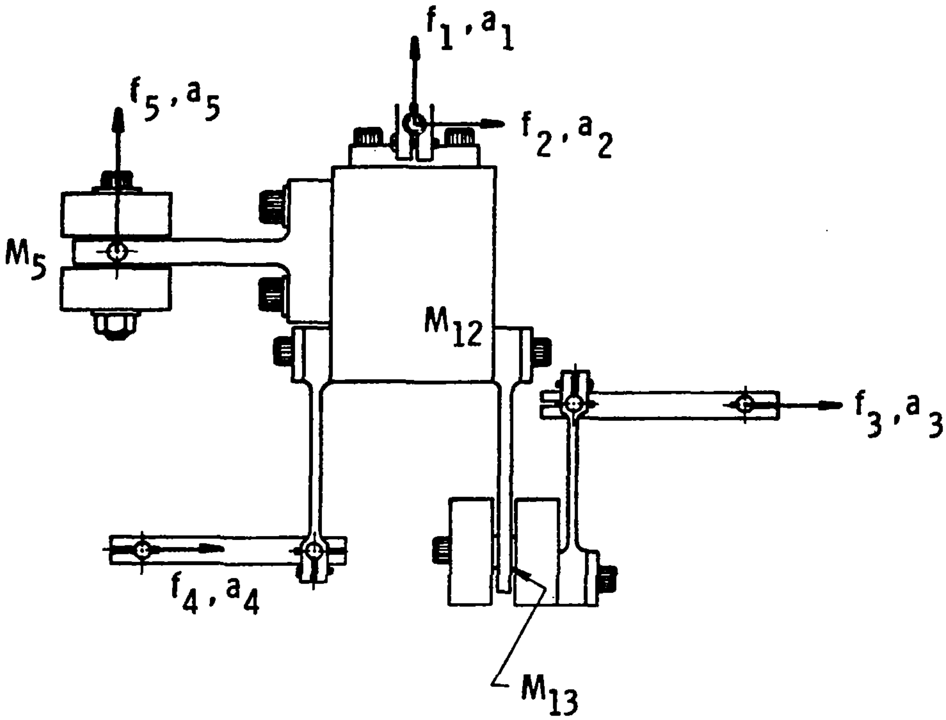


Figure 1. Flexible Payload Model Showing Measurement Coordinate System

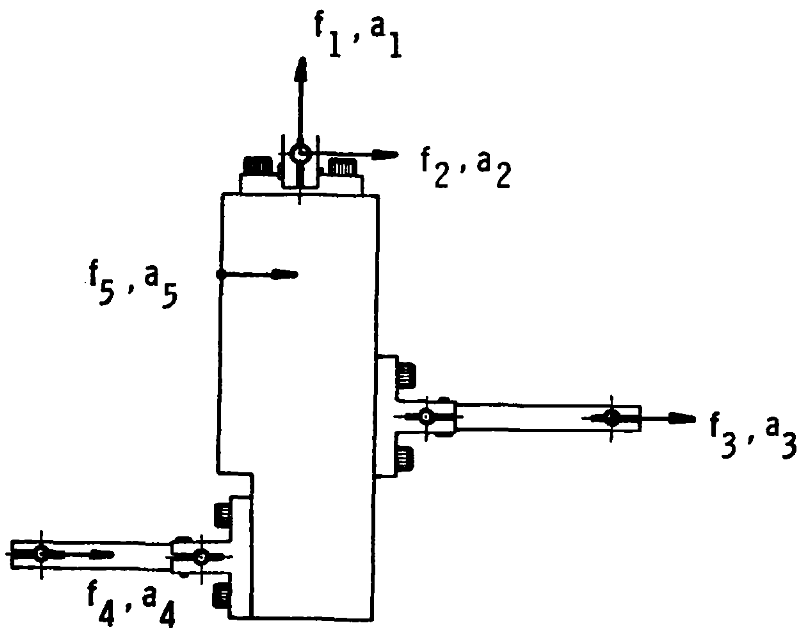
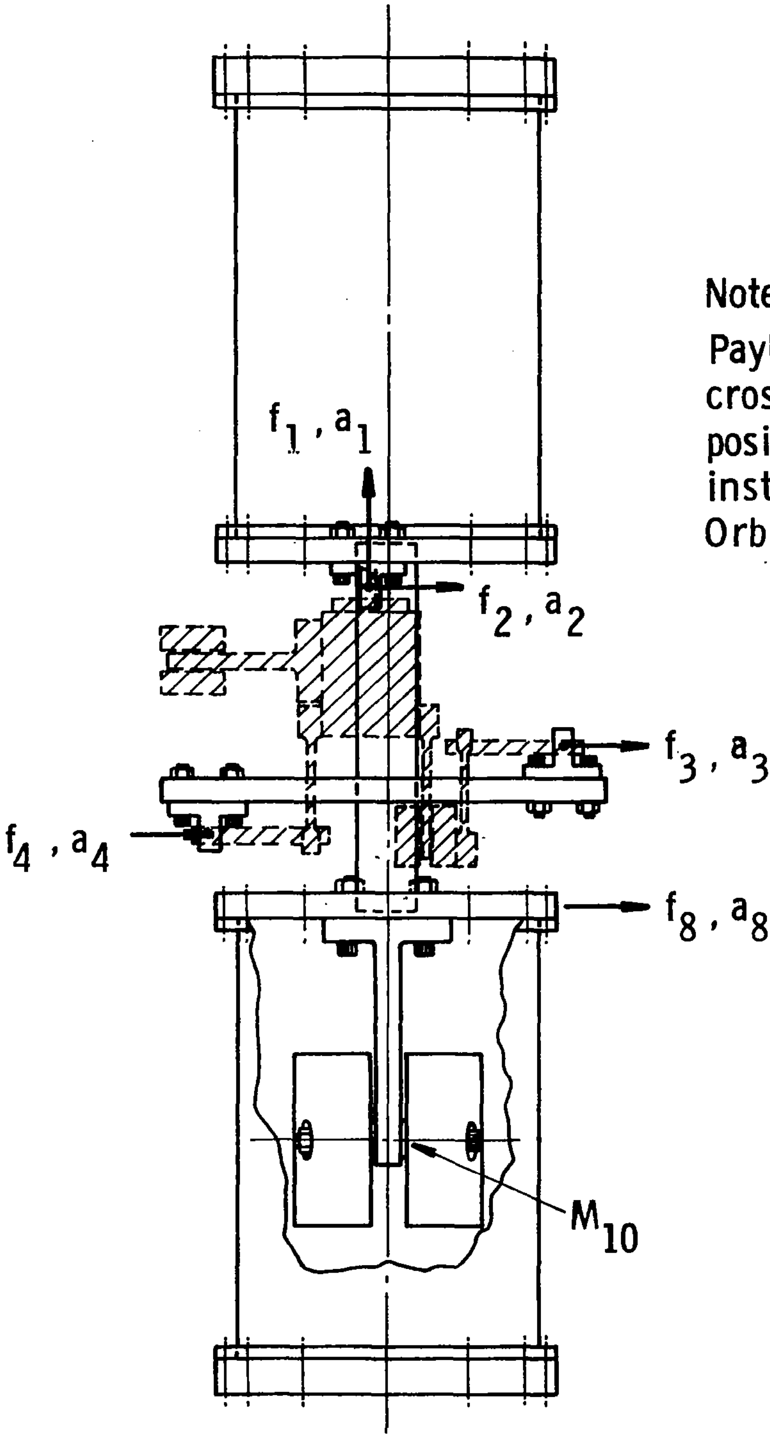


Figure 2. Rigid Payload Model Showing Measurement Coordinate System



Note:
Payload Model is cross hatched in position for installation in Orbiter Model.

Figure 3. Orbiter Model Showing Measurement Coordinate System

$$a_5 = \left[G_2^T\right]\left[H_2 + E_1\right]^{-1}\left\{G_1^T\right\} F_1' \quad (1)$$

where $\left[G_2^T\right]$ is a 1×4 matrix whose elements are the cross admittances of point 5 to excitations at points 1 through 4 of the payload while tested alone, $\left[H_2\right]$ is a 4×4 matrix whose elements are the admittances of the four interface points 1 through 4 of the payload while tested alone, $\left[E_1\right]$ is a 4×4 matrix whose elements are the admittances of the four interface points 1 through 4 of the orbiter while tested alone, and $\{G_1^T\}$ is a 4×1 column matrix of the accelerations at points 1 through 4 of the orbiter while it is tested alone under the input considered for the combined system. Point 8 of the orbiter was arbitrarily chosen as the input point in the earlier study, and F_1' became a single force f_8 at point 8 (points 6, 7, and 9 of the earlier notation were omitted here because they were not needed).

In this study, direct measured admittances were used as the elements of the analytical matrices. Other techniques have been developed by Klosterman and McCelland[2] whereby analytical matrix elements are generated from the experimental data by means of modal equations. No comparison of the two procedures was made.

Typical final results for the system with flexible payload installed, and for the system with rigid payload installed, are shown in Figures 4 and 5, respectively. Note that predicted results are compared with steady state sinusoidal results that were subsequently measured on the respective combined systems in terms of the system admittance a_5/f_8.

B. Transient Test Techniques

In recent years, much interest has been generated in the area of transient test techniques for use in the vibrational analysis of structures. Transient methods of measuring frequency responses have always been appealing due to the very short test time involved; however, until recently, their use had been limited due to the difficulty in analyzing the associated data. The rise of the digital computer as a tool in data analysis has now enabled transient test techniques to become practical. The short test time associated with transient testing not only speeds up test programs but also reduces the affect of time-dependent nonlinearities and drift which are inherent in instrumentation components such as filters, amplifiers, oscillators, etc.

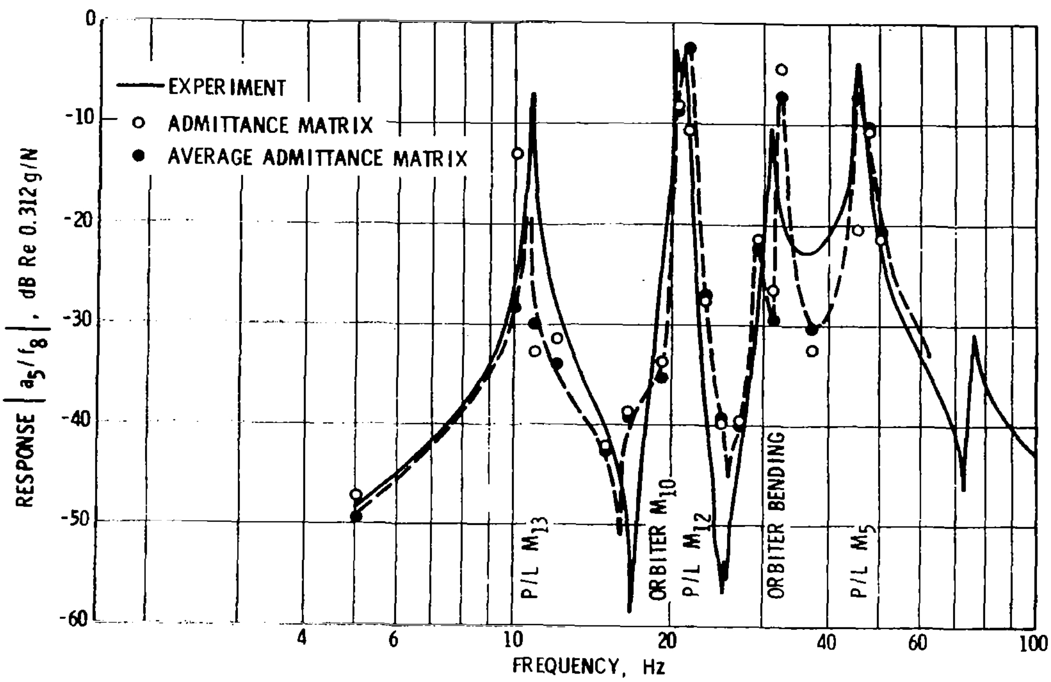


Figure 4. System Response with Flexible Payload Installed - Steady State Method

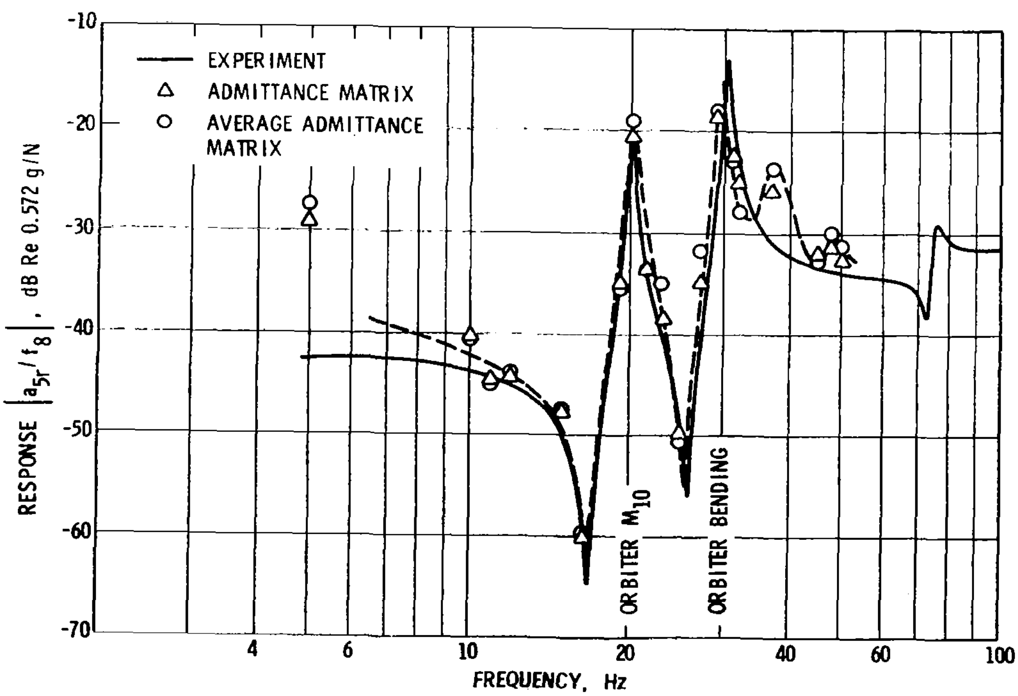


Figure 5. System Response with Rigid Payload Installed - Steady State Method

Briefly, the transient test technique consists of applying a transient excitation to a structure and recording the excitation and response time histories. Typically, pulse type forcing functions or a rapid swept sine transient is used, and both excitation and response time histories are recorded on analog tape. The recorded time histories are then converted to a digital representation via an analog-to-digital converter, and then Fourier transformed. (Of course, the analog tape step can be eliminated if direct on-line digital recording equipment is available.) The frequency response of the structure is then obtained by dividing the response Fourier transforms by the transform of the excitation force, which yields complex admittances. The admittances are subsequently used in prediction equations such as Equation (1). Various papers have been written on transient testing and its related advantages and disadvantages. The basis of transient testing as applied to this program are given in References 3-5.

It has been shown that the accuracy of transient tests is principally affected by: the analog-to-digital (A-D) conversion process, frequency resolution, and method of exciter attachment.[4] Two sources of error exist in the digitization of transient signals. For each sample, the true analog voltage is not recorded but an approximation to the nearest available digital value is made. This is referred to as quantization error. This error is usually insignificant since the size of the interval between adjacent digital values is very small compared to the voltages to be digitized. Finite sampling rate is the second source of error in ditigization. Ideally, a waveform can be perfectly reproduced by taking an infinite number of samples. In practice, however, the sampling rate is determined by the highest frequency present in the data to be digitized. For a fast swept sine wave, a sampling rate of four times the highest expected frequency is adequate to insure that aliasing does not occur. The relationship between record length (τ_m), frequency resolution (Δf), sampling rate (SR), and total number of samples (NS), has been given before by Holmes and White[4]:

$$\tau_m = 1/\Delta f = NS/SR \tag{2}$$

It can, therefore, be concluded that the accuracy available is dependent on the amount of data that can be stored in a computer.

III. EXPERIMENTAL APPARATUS AND PROCEDURES

A description of the instrumentation and data acquisition techniques used for the transient tests will be given in this section. As in the previous effort, the models were suspended in a low frequency support in order to simulate a free-free environment. Figure 6 shows a photograph of the orbiter with flexible payload installed as suspended for the system tests. Similar techniques were used for the individual components. Small piezoelectric accelerometers were used to measure responses at the designated points (Figures 1, 2, and 3), while a transient force excitation signal was applied using a light electromagnetic coil. The exciter coil was capable of excitation down to DC in frequency, and force was calibrated in terms of the armature current. An input accelerometer ring was used to avoid excitation directly through the accelerometer at this point. The ring was bolted to the input point before the accelerometer was mounted inside it. This arrangement avoided distortion of input acceleration signals. Once again, various stabilizers or guides were used as part of the suspension. Also, for the case of the payload, ballast weights were used at the attach points. Each ballast was set at exactly the weight of the small coil plus its connecting link so that all excitation point mass values were properly accounted for. Details including further pictures of this suspension system are given in Reference 1.

Initially, steady state sine sweeps of constant force amplitude applied at one point were conducted and responses of select points recorded on an X-Y plotter. These tests were run to verify that the model dynamic characteristics had not changed due to possible aging since the earlier work. The instrumentation used in this phase was identical to the instrumentation used in the earlier steady state tests (Figure 7 of Reference 1). The acceleration output signals were filtered through a 2-Hertz bandwidth tracking filter, thus improving the signal to noise ratio. The signal was then passed through a log converter to allow plotting of signals having a wide dynamic range.

Data acquisition for the transient admittance tests was performed by the instrumentation system shown in Figure 7. A typical test sequence consisted of applying a 4-second approximately logarithmic swept sine force transient of the form:

$$f(t) = (F_o + F_2 t^2) \sin \left[(\omega_o + A_2 t^2)\, t \right] \tag{3}$$

The frequency limits were set at 5 Hz to 100 Hz, and the input force and response time histories were recorded on analog tape. The signal was

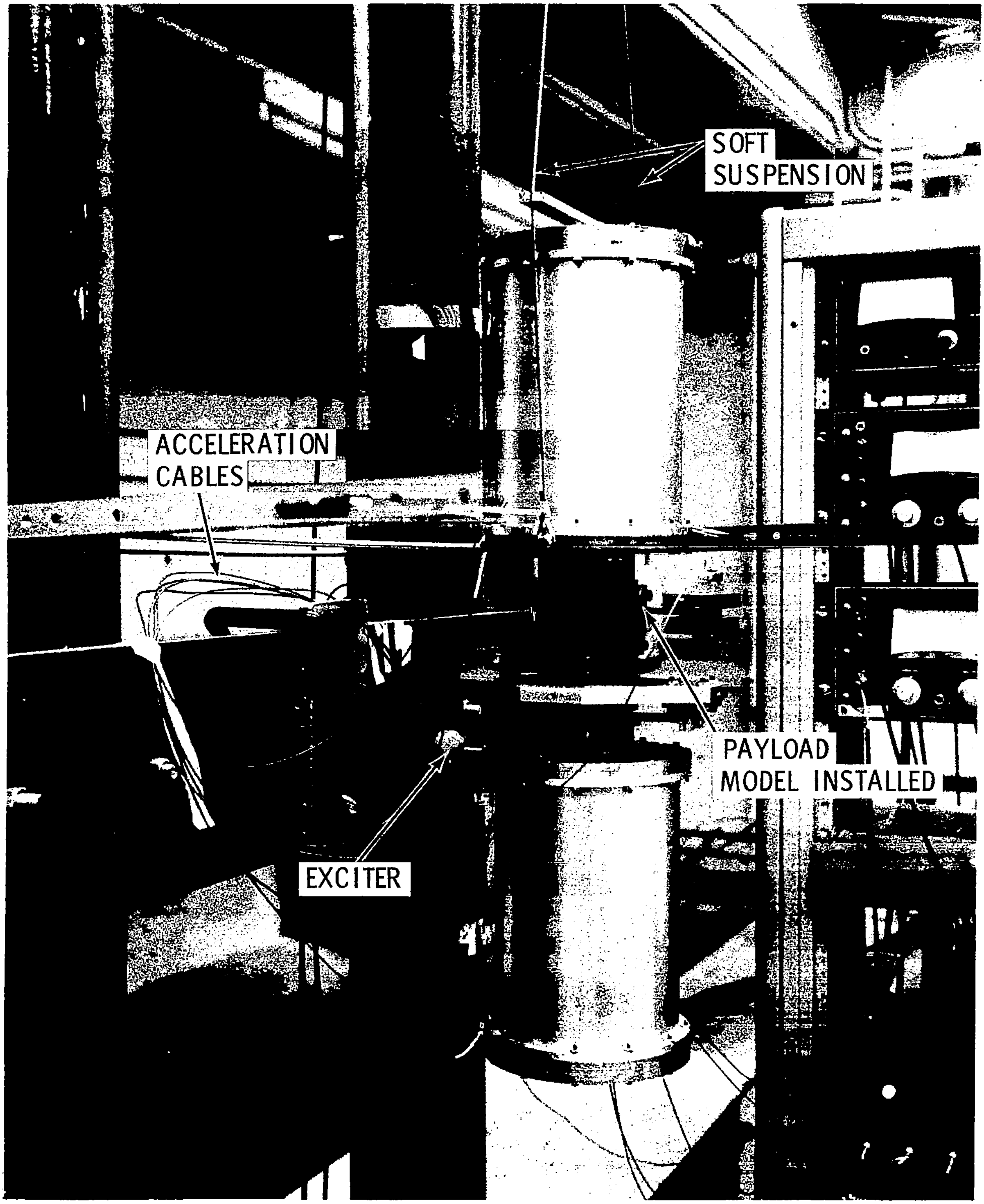


Figure 6. Freely-Supported Test Configuration of System Model with Flexible Payload

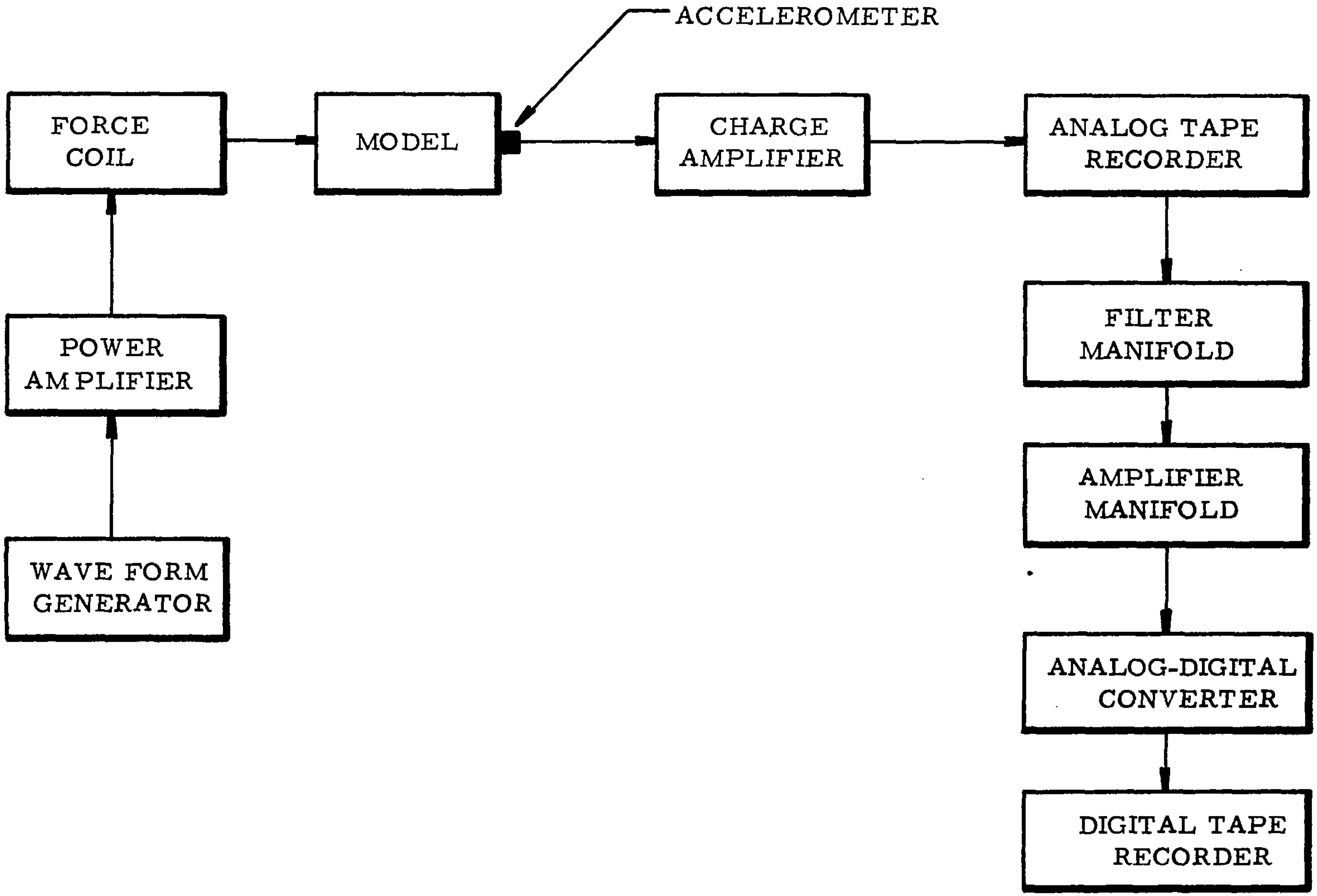


Figure 7. Block Diagram of Instrumentation for Transient Test Measurement

generated by analog components which allowed the first sine cycle to start exactly at zero for $t = 0$. This is a modified form of the transient utilized for the study in Reference 4. Also, the force amplitudes F_0 and F_2 were readjusted for each type of model and excitation position in order to optimize the acceleration signal for some response point to the maximum allowed by the analog tape recorder.

The analog signals were subsequently filtered through 1000 Hz low-pass filters, amplified to improve the signal levels, and then converted to a digital representation using an A-D converter. In performing the digitization of the 4-second transient, a sampling rate of 2048 samples per second per channel was used, resulting in a total of 8192 points per channel. From Equation (2), the frequency resolution (Δf) can be computed as being 0.25 cycles. A frequency of 500 Hz was selected as the upper frequency limit, and a sampling rate of 2048 samples per second provided a sampling rate of four times the highest expected frequency.[4] The digital data was written in blocks of 2048 on a 9-track, 1600 bits per inch density digital tape and input to an IBM 370 computer.

Fourier transforms were sequentially performed on the input force and the response time histories. Admittances were then computed for all of the appropriate force and response time history combinations required for use in Equation (1). As an example, the admittance (Y_{51}) of response of point 5 of the payload to a transient force at point 1 of the payload was obtained from

$$Y_{51}(f) = \frac{A_5(f)}{F_1(f)} \tag{4}$$

where $A_5(f)$ is the Fourier transform of the transient acceleration response at point 5, and $F_1(f)$ is the Fourier transform of the transient force at point 1. A "smoothing" technique was used on the admittance data to reduce scatter. This consisted of a Hanning type averaging process where for either the real or imaginary value of the admittance, Y_{ns} at a given frequency f_n was obtained from

$$Y_{ns} = 0.25\ Y_{n-1} + 0.5\ Y_n + 0.25\ Y_{n+1} \tag{5}$$

The final predicted response of the combined system was obtained by substituting the corresponding computed payload and orbiter admittances into Equation (1). Forced symmetry (averaging of corresponding off-diagonal admittance elements) was incorporated into Equation (1) to improve the results at resonances as was done in the earlier steady state analysis.[1]

It should be emphasized that the above procedure evolved from a series of trial techniques which were eliminated as providing less than optimum results. For example, a force transient of constant amplitude, a linear frequency change rate, use of velocity rather than acceleration response, and a variety of other choices of detailedaspects of the technique were eliminated. In all these cases, it was found that the final form shown in Equation (3) provided the optimum amplitude and frequency sweep rate over the total frequency range. By optimum, we mean that a good response signal level occurred for each part of the test frequency range, without causing excessive vibration amplitudes in the model itself. Also, it was recognized that the dynamic range of an analog recorder is generally not as good as that of an A-D data acquisition system, and that recording of the data directly on line into the digital system would improve dynamic range. However, the use of an analog recorder at this particular stage of development of the transient admittance method provided the following advantages:

- Elimination of the need for dedicating an A-D converter to the experiments over an extended series of intermittent test periods.

- The capability of redigitizing the same event if necessary, at different sampling rates and sampling times (thereby allowing a study of the effects of varying the frequency resolution of the analysis) without having to rerun the entire experiment.

IV. TRANSIENT TEST RESULTS

A. Elastic and Rigid Payloads

Examples of comparisons of magnitudes of acceleration admittances obtained from steady state tests and those obtained from transient excitation techniques is given in Figures 8 and 9 for the flexible payload and rigid body payload, respectively. Various structural resonances are identified for the elastic components where appropriate. Similar curves were obtained for excitation at all other points of each of the payloads.

As shown in Figure 8, the transient excitation data agrees very closely with the steady state data in the frequency range of 20 to 80 Hz. However, below 20 Hz there is significant disagreement. It was noted that Holmes and White(4) experienced a similar problem. The source of this error was not clear at this point. Furthermore, the full impact of the discrepancies could not be ascertained until data from all positions were acquired, and the final predictions of the combined system performed. Therefore, it was decided to proceed with the predictions, and to investigate sources of error subsequently. This will be discussed in a later section of the report.

The comparison of the magnitudes of acceleration admittances shown in Figure 9 displays a fairly constant differential of 1-1/2 db. This discrepancy may be a calibration error in either the steady state data or the transient excitation data. The results for the rigid body payload should, of course, be constant over the entire frequency range. Similar results were achieved for the other admittances that were determined.

B. Orbiter

A comparison of magnitudes of acceleration admittances obtained from steady state tests and from transient excitation techniques is given in Figure 10 for the orbiter. The transient excitation data agrees very closely with the steady state data, especially in the areas of the two strong resonances, 21 Hz and 34 Hz, respectively. Again, however, there is some disagreement in the low frequency range (5-15 Hz).

C. Combined System

Figures 11 and 12 show a comparison of directly measured admittance results for the combined system with the flexible payload

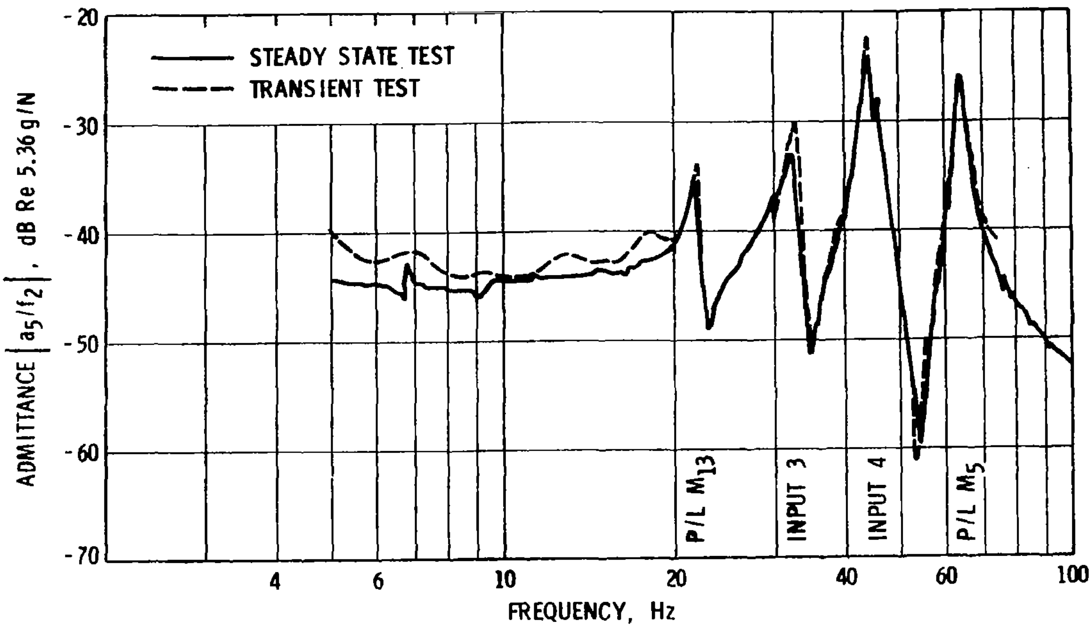


Figure 8. Experimental Response for Flexible Payload

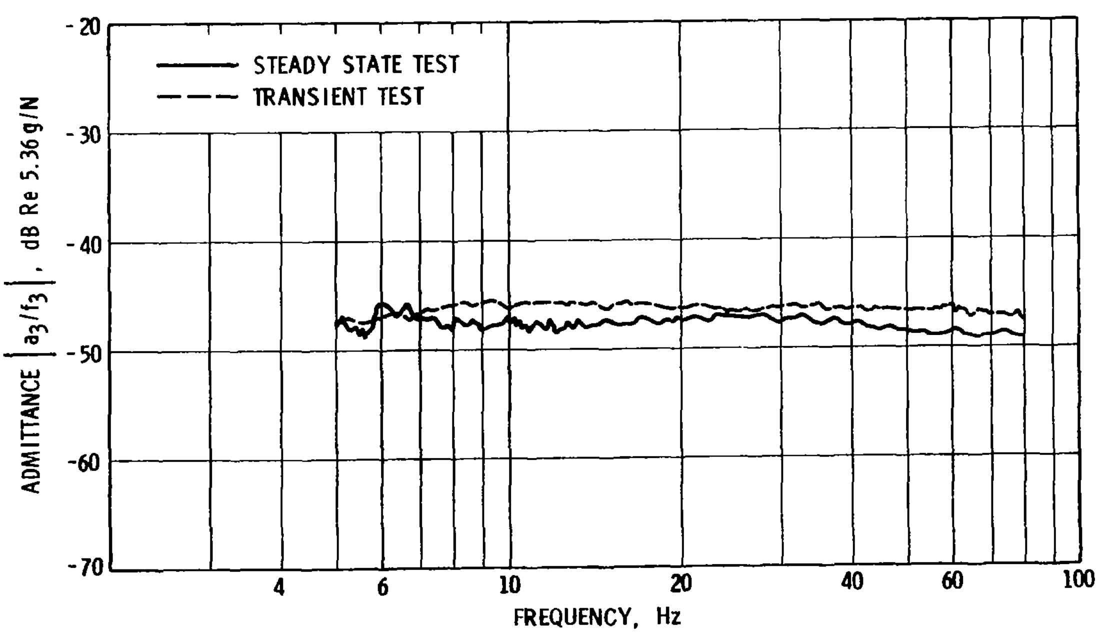


Figure 9. Experimental Response for Rigid Body Payload

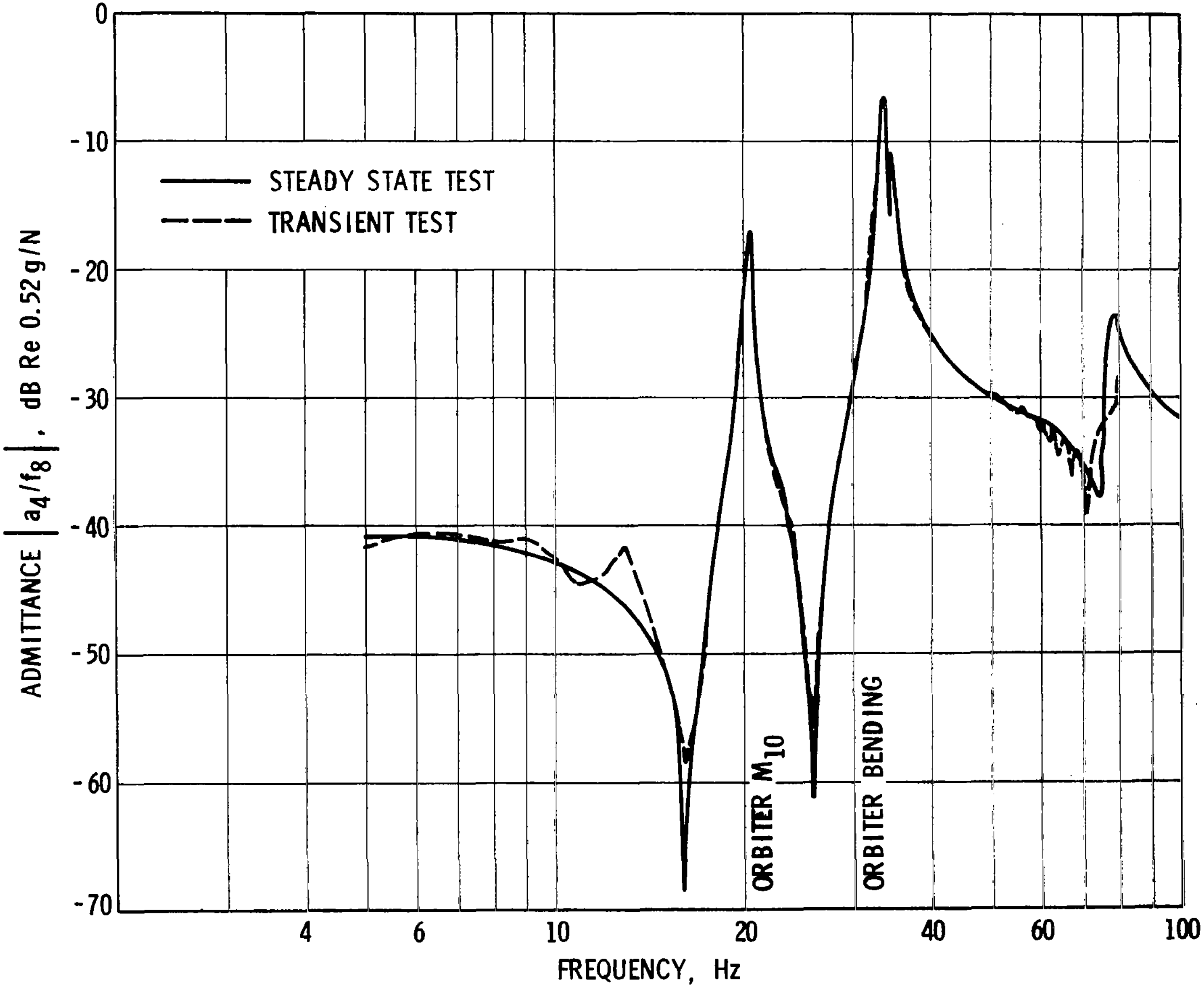


Figure 10. Experimental Response for Orbiter Model

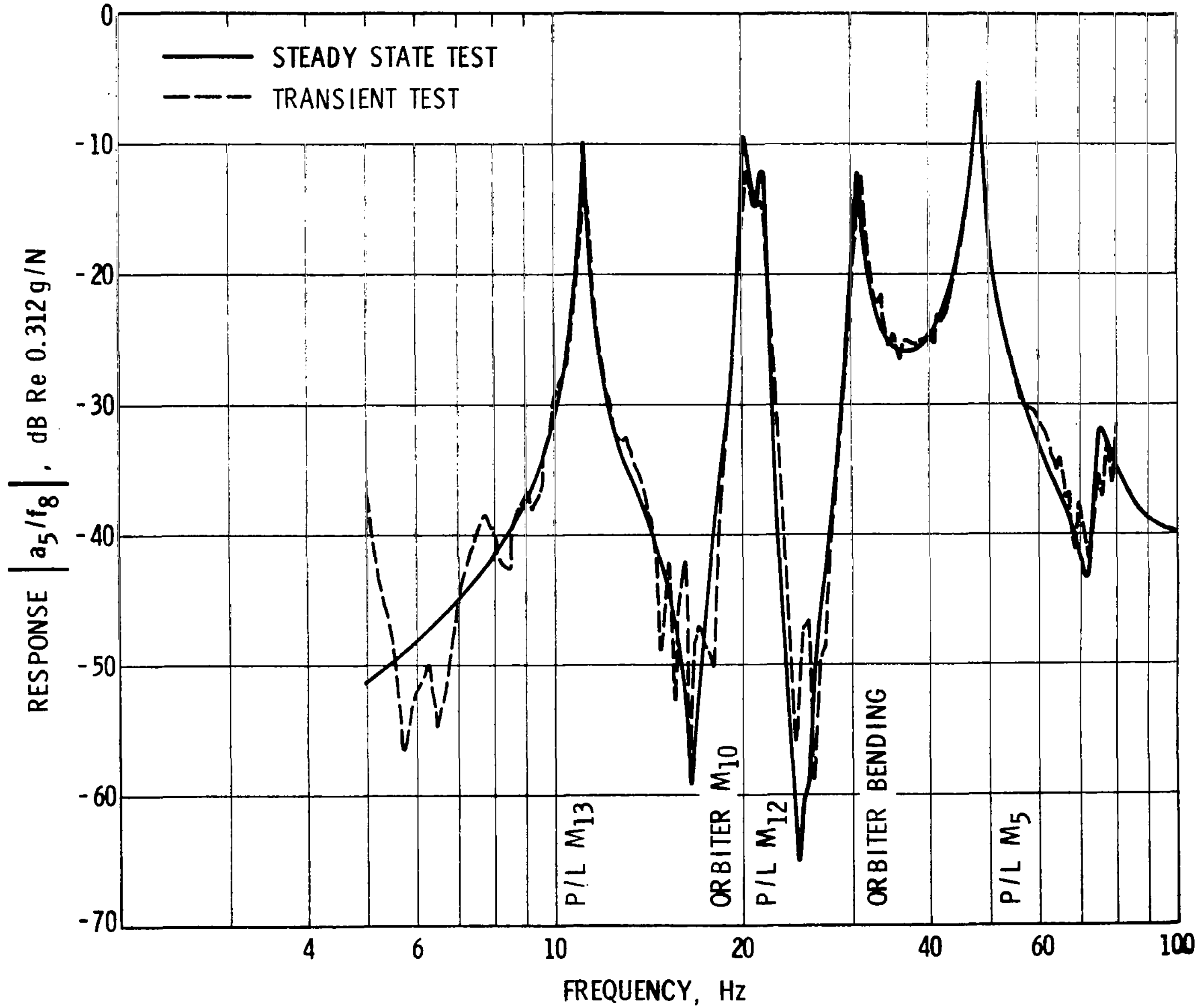


Figure 11. System Response with Flexible Payload Installed

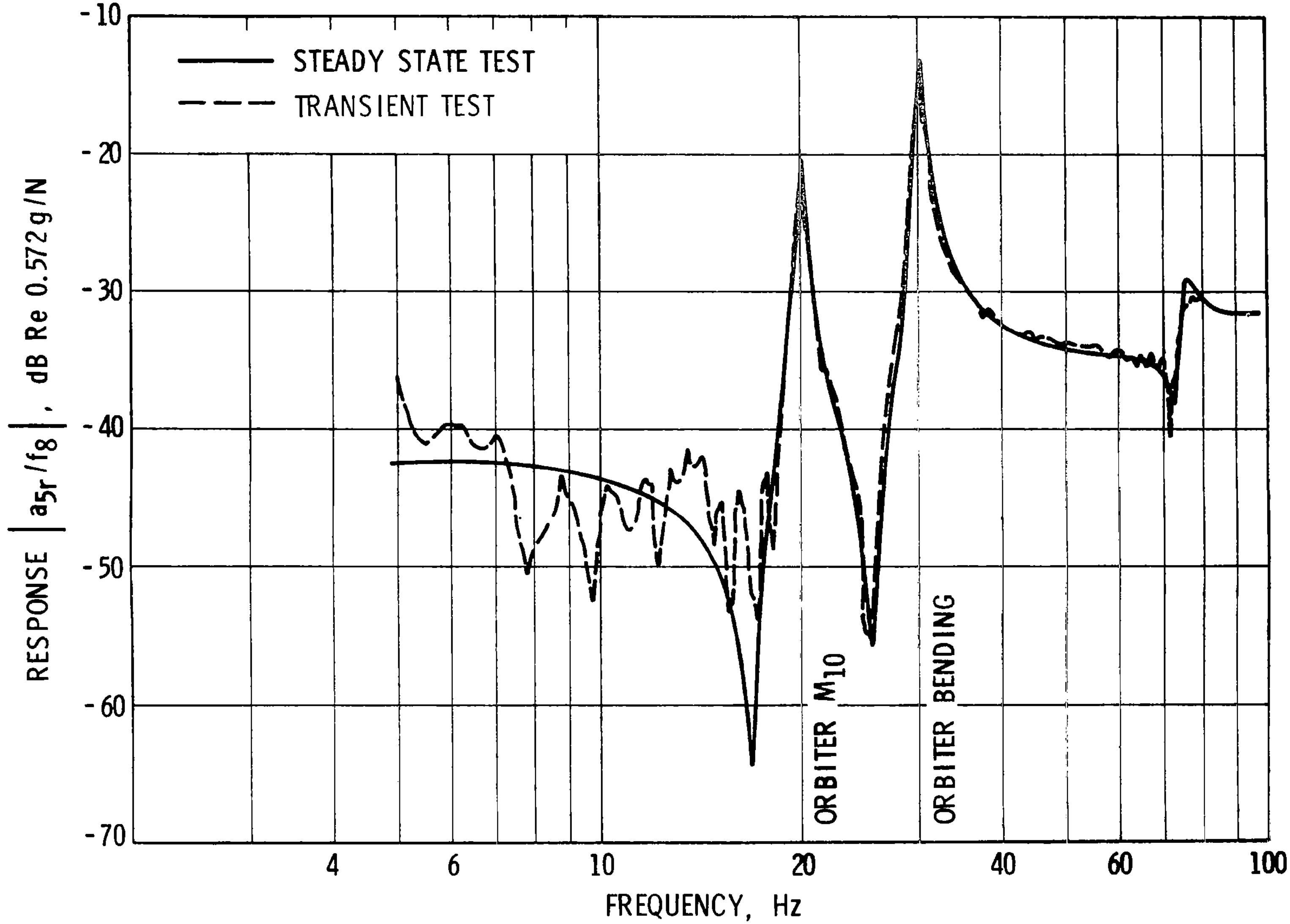


Figure 12. System Response with Rigid Payload Installed

installed and the combined system with the rigid payload installed. These directly-measured transient test results for the combined system were not necessary to prove the validity of the transient test/admittance matrix prediction method; however, they were conducted to provide a better idea of the accuracy of the transient test technique. Once again, the agreement between steady state and transient testing techniques is very good in the frequency range of 20 Hz to 80 Hz, but falls off at the low frequency range in both configurations and at the anti-resonances for the combined system with flexible payload.

V. RESULTS FOR PREDICTION OF SYSTEM RESPONSE

Figures 13, 14, and 15 show a comparison between steady state and the final predicted results for the combined system with:

- o flexible payload installed,
- o rigid payload installed, and
- o theoretically calculated admittance values for the rigid payload.

The theoretical admittance values for the rigid payload were calculated using Equation (19) of Reference 1. The final predicted results for the three aforementioned configurations were calculated based on Equation (1), and predict the acceleration response of the payload at point 5 from an excitation applied to the orbiter at point 8.

Discrepancies near some of the resonance peaks above 15 Hz for the system with elastic payload (Figure 13), appear to reflect errors in admittance measurements on the elastic payload itself, rather than on the orbiter model. This assertion is supported by noting that similar errors do not occur to such a degree for the rigid payload with measured admittances (Figure 14), and even to a lesser degree for the rigid payload with theoretical payload admittances along with measured orbiter admittances (Figure 15). Thus, the structural complexity of the payload appears to influence the final predicted results.

Generally, as can be observed from Figures 13, 14, and 15, the final predicted results and the steady state results compare reasonably well in the frequency range of 15 Hz to 75 Hz, but again disagree in the lower frequency range. The extent of this disagreement can best be shown in Figure 13, where the lower frequency M_{13} payload mode near 11 Hz is not predicted well at all. In view of the previous similar trends in data measured for the individual components, it was judged that these discrepancies result from the inadequacies of the transient admittance data below 15 Hz for each of the components, and not from the admittance matrix prediction technique itself. However, at this point it was not clear whether the discrepancies were caused by a signal-to-noise ratio problem, by some peculiarity in the digital data acquisition and processing of the Fourier transform, or by some peculiarity of the forcing function. Therefore, some subsequent analyses were performed in these areas, and the results are given in the following section.

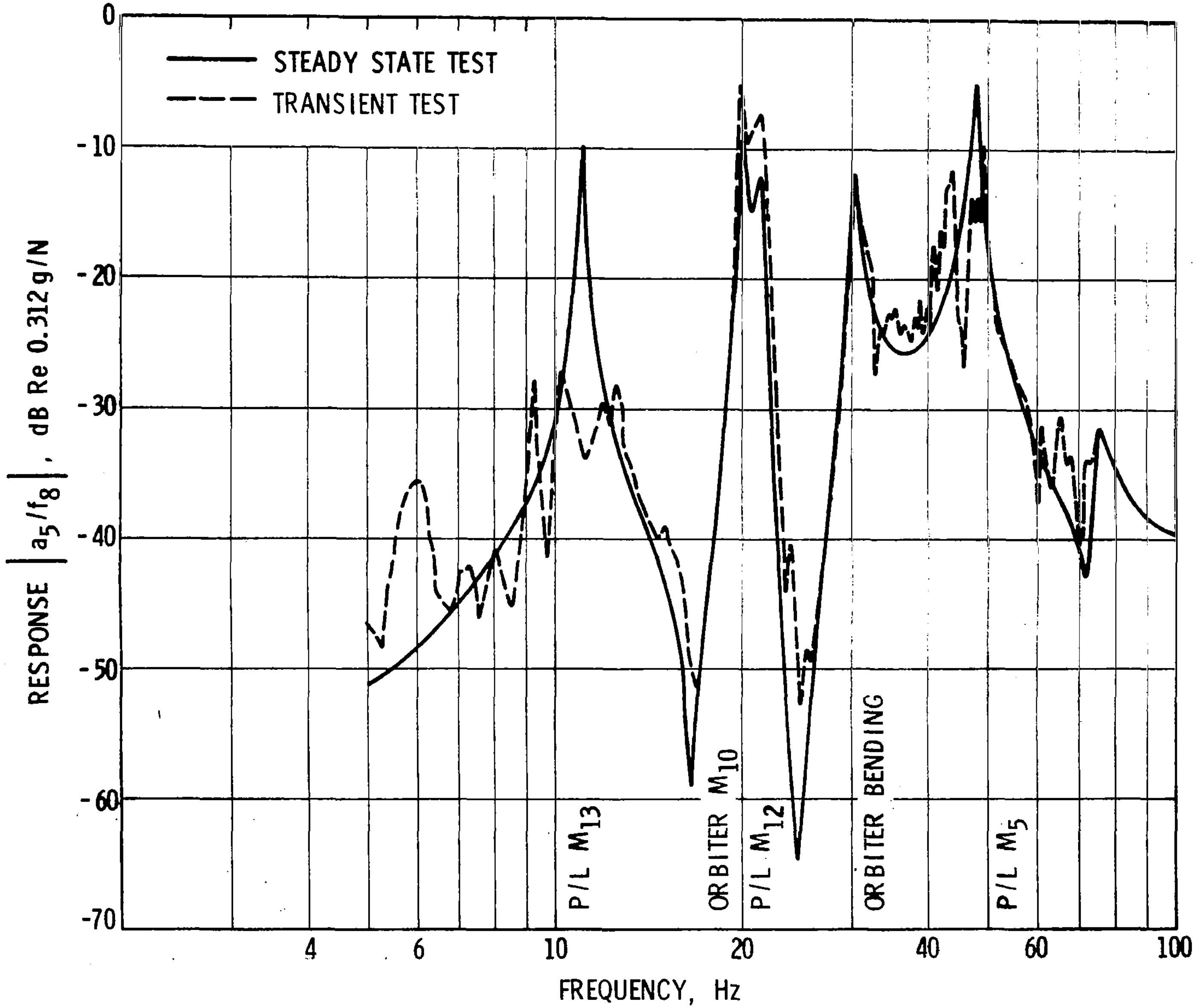


Figure 13. System Response with Flexible Payload Installed

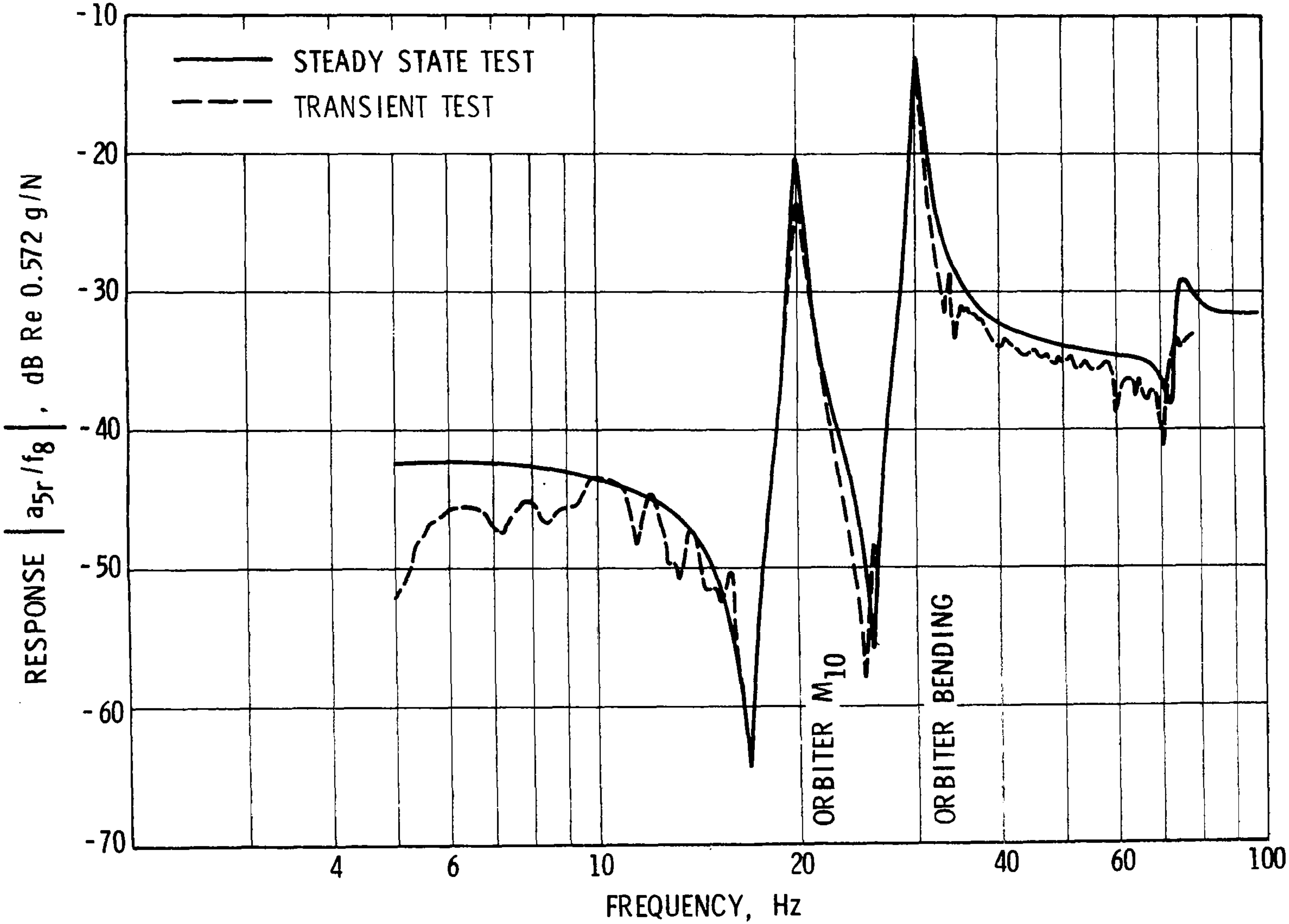


Figure 14. System Response with Rigid Payload Installed - Measured Payload Admittance Matrix

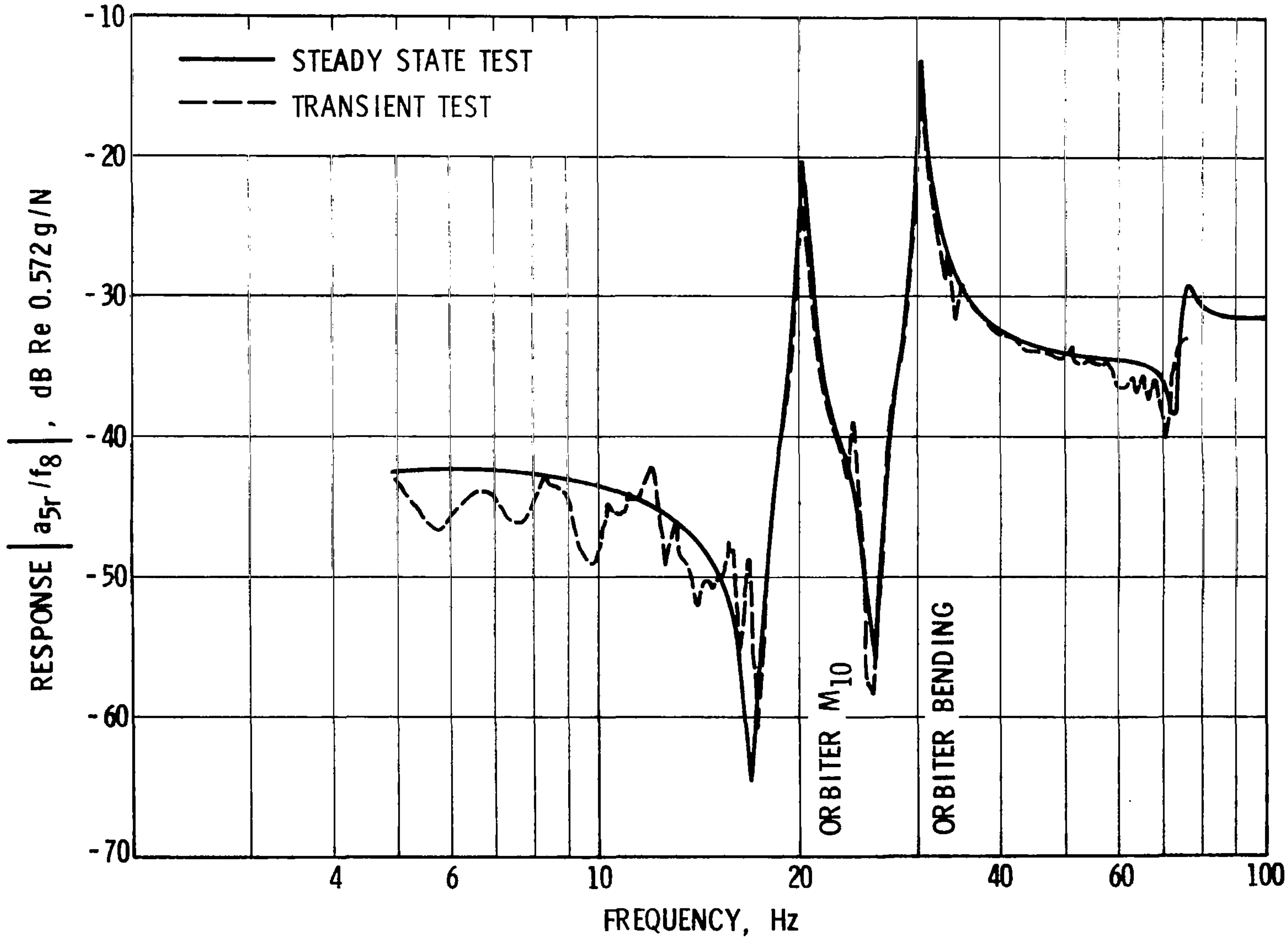


Figure 15. System Response with Rigid Payload Installed - Theoretical Payload Amittance Matrix

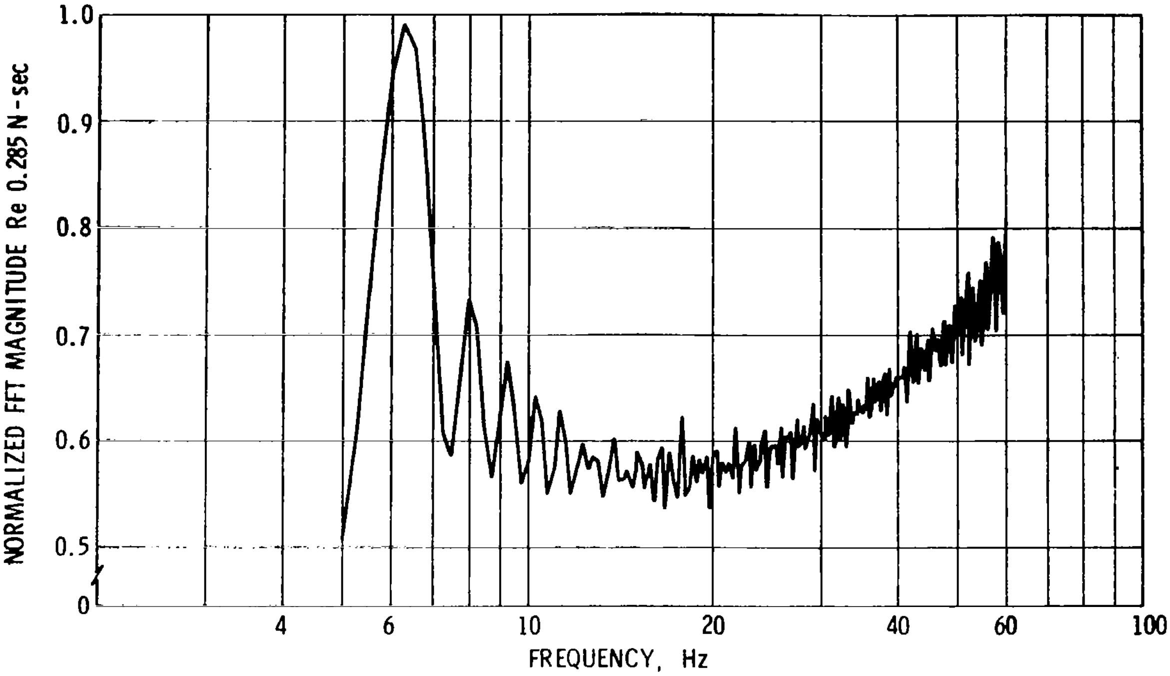
VI. REFINEMENT OF TECHNIQUE

At this point, it was obvious that the discrepancies of the component measured admittance data in the low frequency range could jeopardize the possible use of the transient test method for prediction of combined system response. Therefore, several subsequent attempts were made to determine the source of the discrepancies. These investigations were based on additional measurements made on the system with rigid body payload installed. This configuragion, rather than the elastic payload combination, was chosen, since it was not influenced in the low frequency range by the presence of the elastic payload mode near 11 Hz. However, the results are applicable to transient tests on both the payload and the orbiter as components, in general.

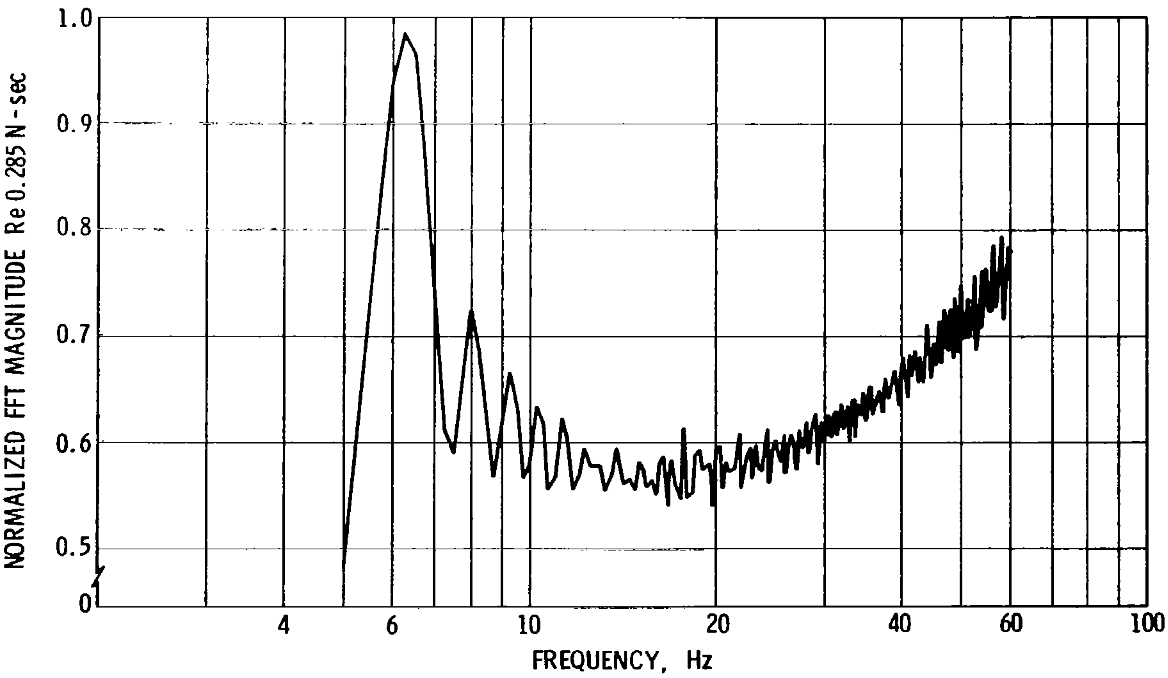
The subsequent error analysis involved the following steps:

- Analysis of the force and acceleration FFTs of several runs to determine variability.
- Performance of transient tests over a sweep range of 5-25 Hz instead of 5-100 Hz for the 4-second interval to determine whether a longer time period in the low frequency range would improve signal-to-noise ratio.
- Averaging of transfer functions from five sequential transient tests at a given position to reduce random noise content.
- Averaging of transfer functions from ten sequential transient tests at a given position to reduce further the random noise content.
- Provision of direct on-line digital recording of transient data to eliminate signal-to-noise problems associated with the analog tape recorder.

Analyzing the force and acceleration Fourier transforms yielded valuable information in the areas of variability. Figures 16 and 17 show the magnitudes of the Fourier transforms of the force input and acceleration, respectively, for two separate sequential transient tests. From Figure 16, it can be seen that the variation between the Fourier transforms of the forcing functions of the two runs is negligible. However, a comparison of the corresponding acceleration Fourier transforms of the two runs, as shown in Figure 17, indicates a significant variation between runs in

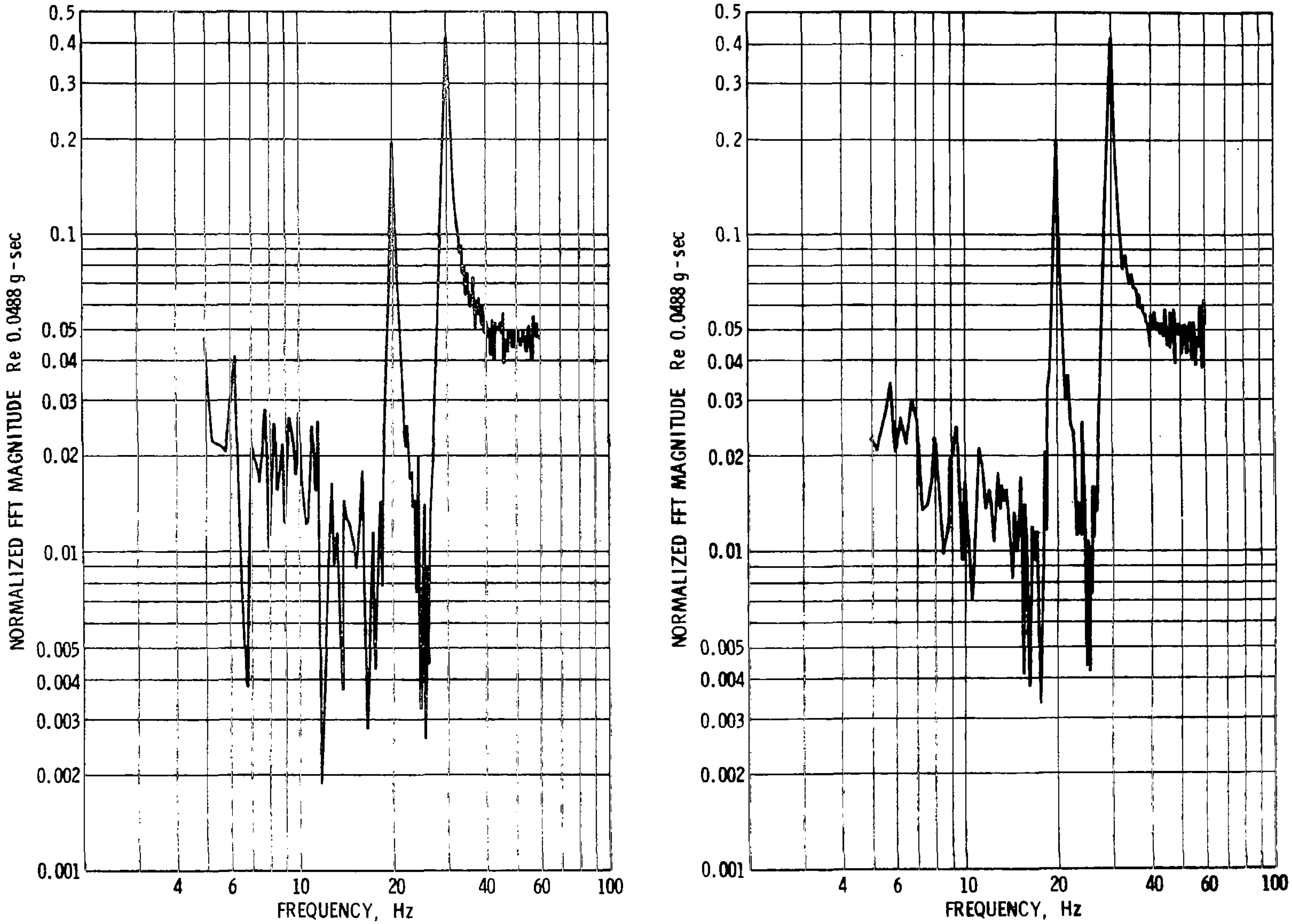


(a) Test Run No. A



(b) Test Run No. B

Figure 16. Comparison of Force Fourier Transform



(a) Test Run No. A

(b) Test Run No. B

Figure 17. Comparison of Acceleration Fourier Transforms

the lower frequency range. This variability in the acceleration transforms had the characteristics of random noise. It was obvious that this variability was caused by a signal-to-noise ratio problem associated with the dynamic range limitations of the analog tape recorder or of the acceleration measurement electronics, or by insufficient time being spent in the low frequency range during the transient test.

In order to resolve these sources of low frequency variability in the data, additional transient tests were performed on the combined system with the rigid payload installed, but using a sweep range of 5-25 Hz instead of 5-100 Hz in the 4-second interval. It was felt that this type of test would indicate whether more time was required in the low frequency range for the swept sine transient. Results of this test are given in Figure 18, and show that the correspondence between the computed transient admittance data and the steady state data did not improve. Analyses of the force and acceleration Fourier transforms of two transient tests were performed, and again, the variability between the force Fourier transforms was negligible but the variability between the acceleration Fourier transforms was significant. These findings verified the problem as being one of lack of sufficient dynamic range in signal-to-noise ratio, and it was felt that a multiple run averaging process would improve the agreement between the transient test data and the steady state data.

The multiple run averaging technique showed very distinct improvement of the data. This modification involved taking five separate runs at a given force position, recording the transient force and response individually, digitizing the individual run and computing their transfer functions, and finally taking a linear average of the real and imaginary parts respectively for the transfer functions of the five runs. Figure 19 shows an example of results where this was done for the system with rigid payload installed. This response should be compared with that in Figure 12, which was computed from data taken on a single transient run. It can be seen that the correspondence with the steady state data has improved throughout the frequency range, the noise level of the data has been reduced, and a much lower scatter of data occurs below 15 Hz.

Since the 5-run averaging technique proved successful in reducing the noise level in the data, it was felt that an averaging technique involving 10 runs would further improve the agreement between the transient admittance data and the steady state data. Ten sequential independent runs were performed on the combined system with the rigid payload installed, with a frequency range of 5 Hz to 25 Hz in the 4-second interval. The data recording and manipulation techniques were the same as those

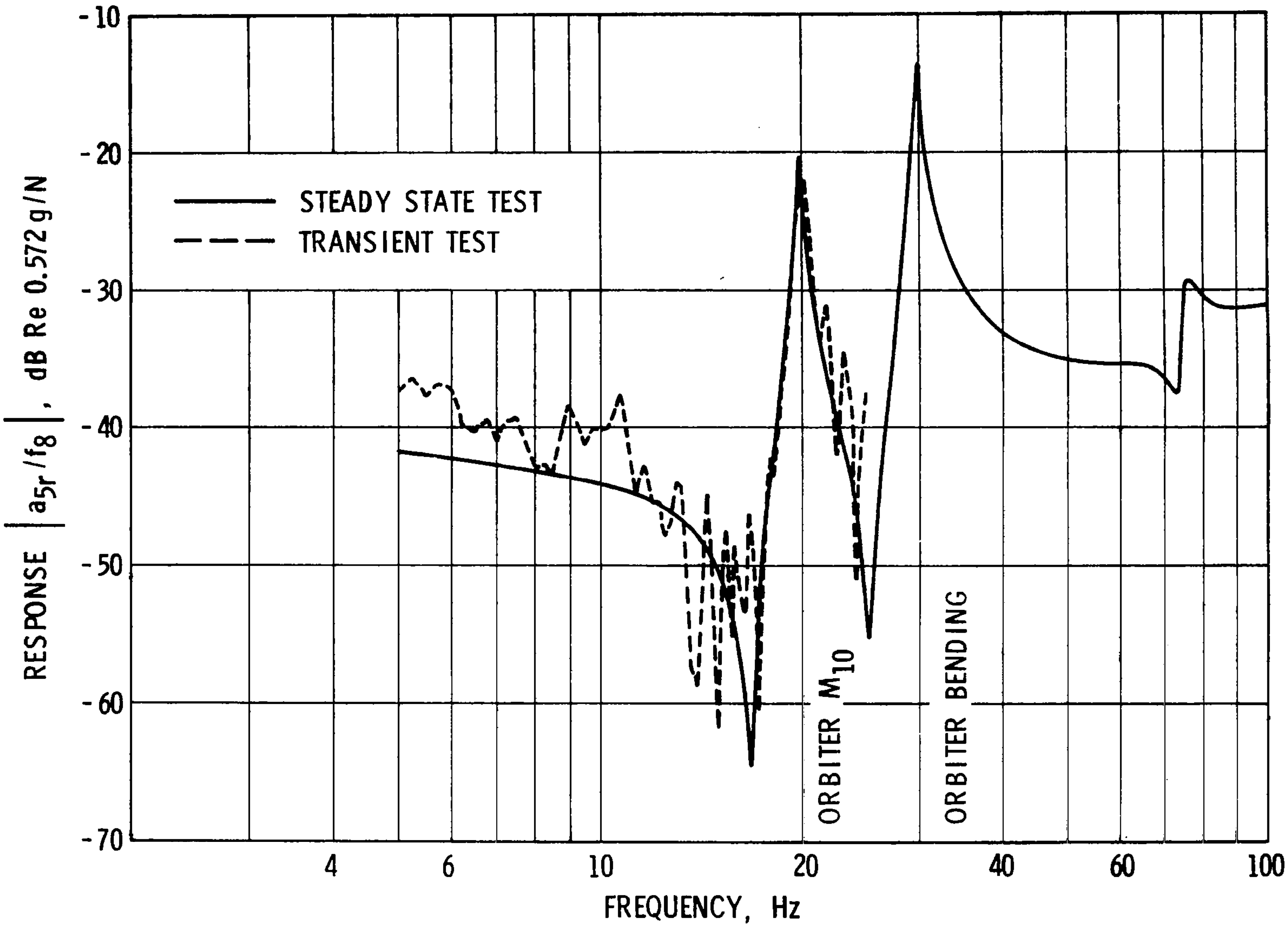


Figure 18. System Response with Rigid Payload Installed (5 to 25 Hz)

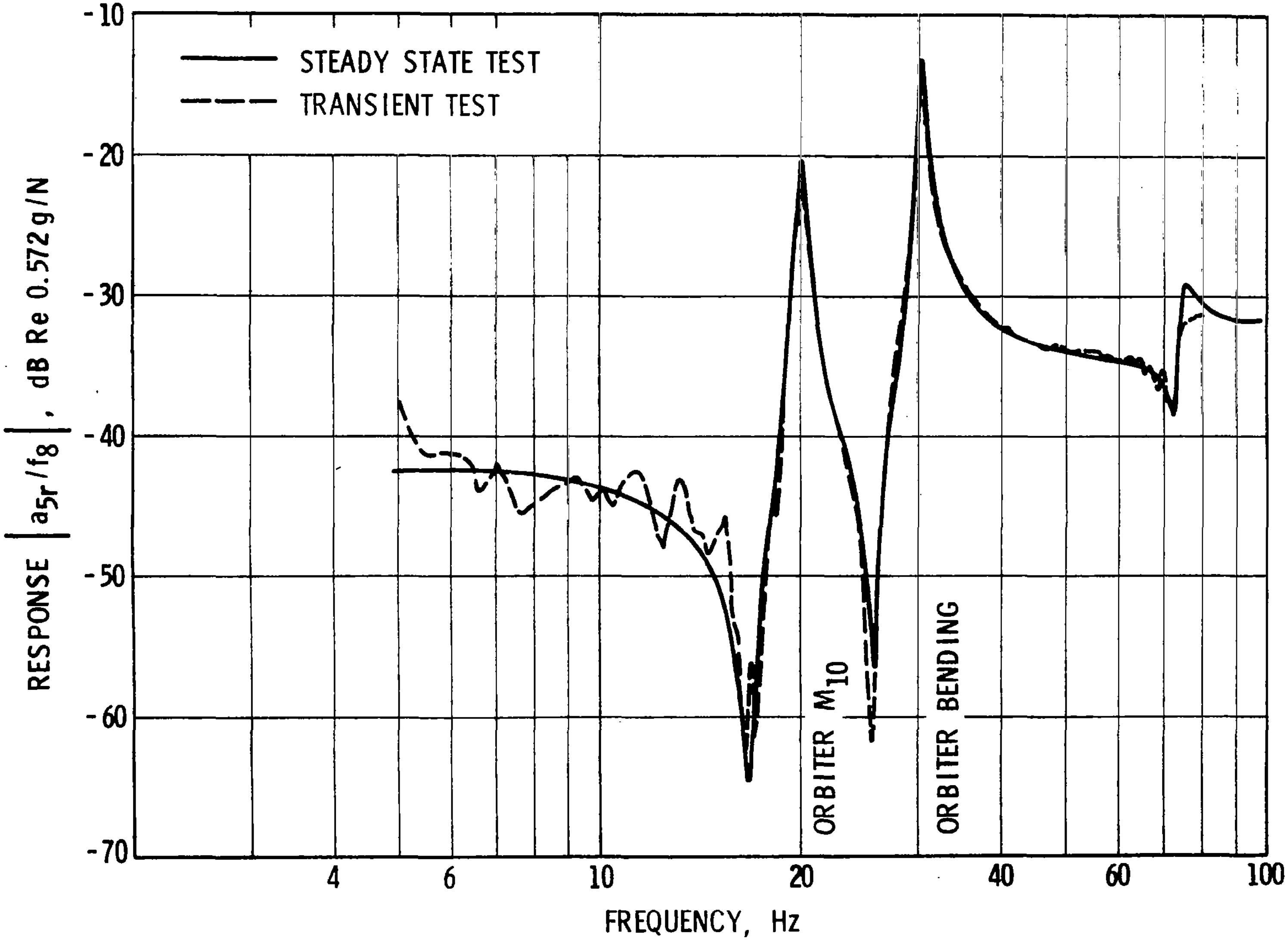


Figure 19. System Response with Rigid Payload Installed - Averaging Method (5 Runs, 5 to 100 Hz)

used in the 5-run averaging. Results of the 10-run averaging technique are given in Figure 20. This response should be compared with those in Figures 18 and 19. It can be seen that the 10-run averaging technique netted only a slight improvement in the agreement between the computed transient admittances and the steady state data. It is felt that such a minor improvement does not justify the cost and time involved in the averaging of 10 runs. It appears from the results obtained that the 5-run averaging technique is adequate in reducing the noise level in the data.

Since the dynamic range of an A-D converter system generally surpasses that of an analog tape recorder, it was felt that recording the transient data directly on-line would result in a reduction of the noise level in the data. The direct on-line recording procedure consisted of testing the model using the same transient testing techniques but bypassing the analog recording step and reading the input and response time histories directly into the digital converter. Results of this test showed an improvement for the prediction of peaks or resonances; however, the noise level in the lower frequency range remained basically the same. This result was contrary to expectation, and a detailed investigation of the associated experimental electronics, i.e., accelerometers and charge amplifiers, etc., was performed. It was found that the noise floor level of the electronics was nearly the same as that of the tape recorder. Thus, the comparable noise levels in the data taken with and without the analog tape recorder was accounted for.

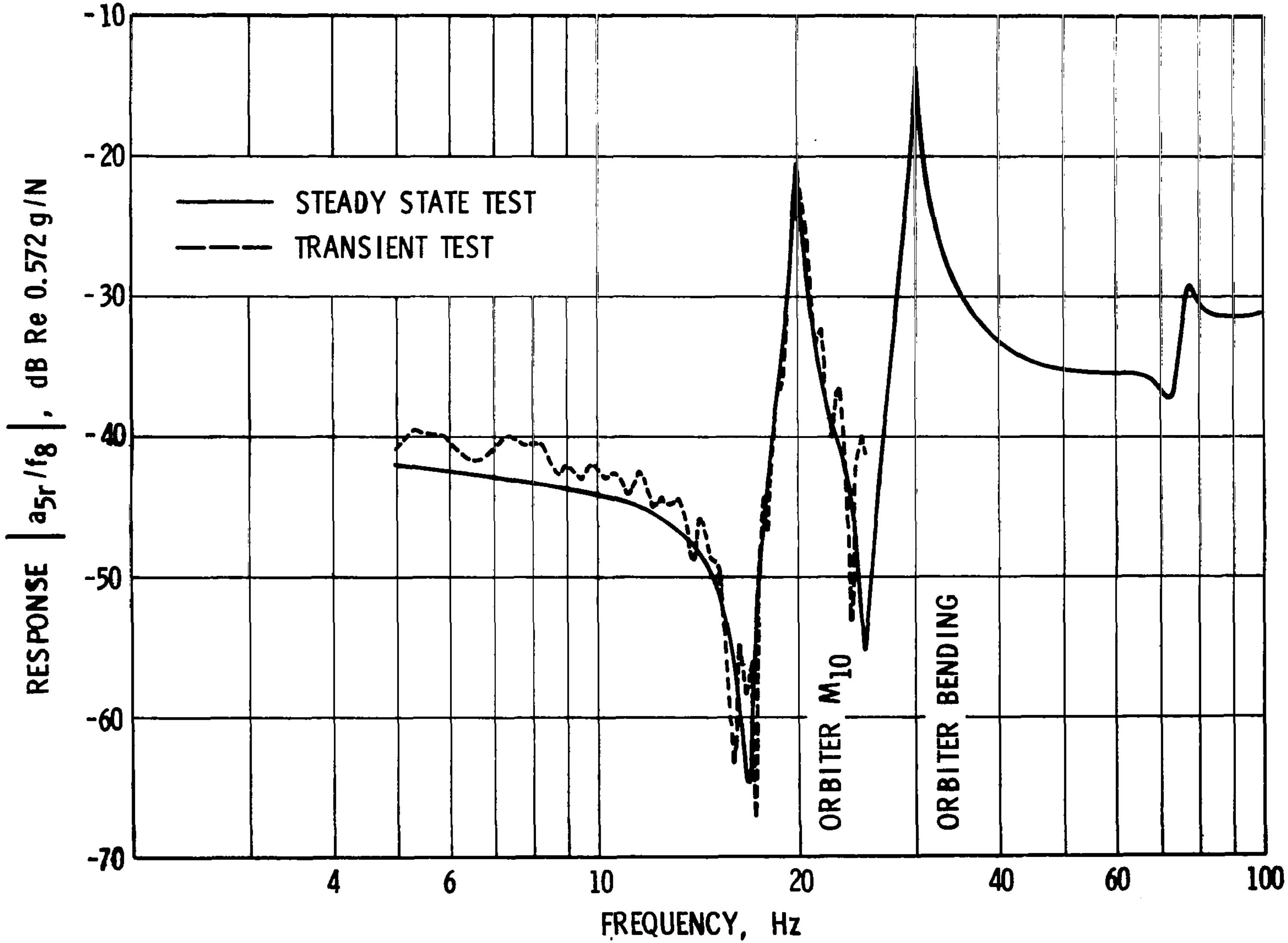


Figure 20. System Response with Rigid Payload Installed - Averaging Method (10 Runs, 5 to 25 Hz)

VII. COMPARISON OF TRANSIENT AND STEADY STATE METHODS

Results of these two methods of system response prediction can best be evaluated by comparing Figures 13 and 14 with Figures 4 and 5, respectively. In both cases it can be seen that a better overall correspondence of predicted and measured data has been achieved by the use of the transient testing technique.

The most obvious advantage of the transient technique is the short time interval required for a data run—a matter of seconds compared with hours for the steady state method. At the same time, by digitizing the time histories and obtaining the Fourier transforms, a far greater increase in frequency resolution is possible. Note that only 19 frequency points were obtained in the earlier work, while a 1/4-Hz resolution was maintained from 5 to 100 Hz in the present work (i.e., 380 frequency points), and this parameter can be controlled at will during the data processing phase. Shorter test time also reduced drift in the data acquisition equipment and its influence on data errors.

In spite of the above comments about testing speed with the transient method, one must also recognize that multiple runs are necessary so that averaging can be performed. However, the time required for even up to 10 runs is still negligible compared to that involved for acquiring steady state data. Because of the increased frequency resolution and the requirement for Fourier transforms, the data handling problem is expanded considerably, and the appropriate computer size and time required for digital processing is influenced accordingly.

In retrospect, it appears that neither the transient nor the steady state method gave a satisfactory prediction of the M_{13} payload mode near 11 Hz for the elastic payload installed in the system. Figure 4 indicates that the average admittance matrix method did not predict the peak in the steady state tests. At the time it was assumed that a peak would have been found with more frequency points. This assumption may or may not be valid, and if not, the indication is that this particular mode is very sensitive to measurement error. This sensitivity is probably related to errors made on the payload measurements, rather than those on the orbiter. The failure of the transient method for predicting this mode results from the data scatter in all measurements below 15 Hz, and it would appear from the results shown in Figure 19 that averaging of multiple runs should improve the chances for providing better predictions in this range. This assertion could be checked by rerunning averaged admittance results for all component positions, and then subsequently using the averaged data to predict the system response. Contractual limitations precluded accomplishment of this effort.

Careful, but different efforts must be pursued in maintaining adequacy of data dynamic range when using the transient test technique. For steady state methods, adequate dynamic range is assured through the use of tunable narrow bandpass filters. These, of course, cannot be employed with the transient method. Ultrasensitive accelerometers, along with the use of a direct on-line analog-to-digital data acquisition system should be considered. Likewise, an immediate playback and monitor capability should be included on the data acquisition system.

The results of this study imply quite clearly that, if the above improvements are included in the acquisition of the transient data, then the admittance method should provide a powerful means of predicting combined system response.

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